A Technical Basis for an Integrated Surveillance Program for Materials in Long-term Storage

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Background

- Large quantities of excess plutonium needs to be stored safely until the Fissile Materials Disposition program can handle the material.
- To assure that these materials will be stored safety, the DOE has established standard for Pu-bearing materials up to 30 wt% fissile material (metals and oxides) stored in double-welded stainless-steel containers.
- The stated purpose of that standard:

Reduce Risk !

> "These criteria provide a basis for assuring that plutonium-bearing materials at DOE facilities are converted to safe and stable forms and placed in storage in packages designed to maintain their integrity with minimal surveillance under anticipated handling, shipping, and storage conditions until final disposition of the materials."

Introduction - What is Risk?
Defining Risk

"Risk" is the fact that
something *bad* *can happen*

Scenario Analysis

Consequence Analysis

Statistical Analysis

Uncertainty in these areas leads us to "Perceived Risk"

"Perceived Risk" is the what we **think** regarding
something *bad* *can happen*

In fact, our goal is to reduce both.

What the Standard Says

- Materials the standard applies to:
  - → **At least 30 wt% Plutonium and Uranium**
  - → **No fines, no liquids, no organics, no moisture**
- The Container
  - → **Two, nested, welded stainless-steel containers**
  - → **Minimum design pressure of 700 psig**
  - → **Leak-tight by ANSI standards**
- The Contained Materials
  - → **No more than 5 kg**
  - → **Must be similar materials**
- Surveillance (must have a plan)
- Documentation (amount of type)
- QA (must have a system)

So how does this element reduce risk?

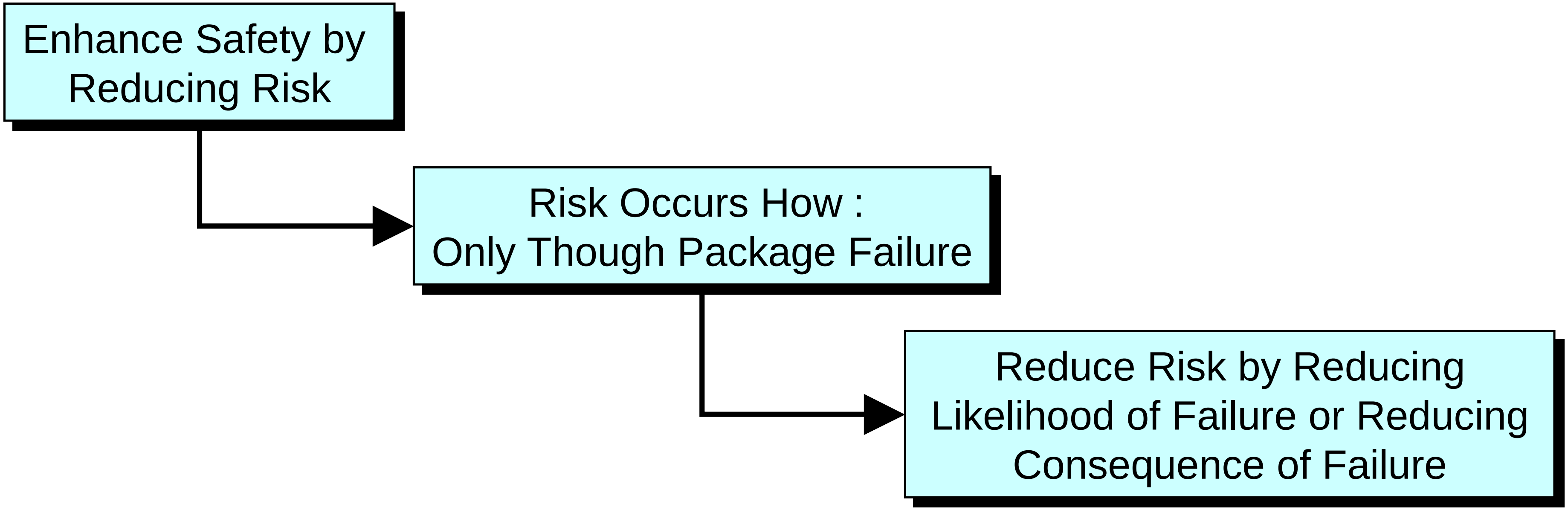
Why a Surveillance Program: I.E., What is the Purpose

The Surveillance Program itself can only reduce “perceived risk”, though it may provide information that allows for the reduction in actual risk.

HOW

- To ensure our presumption of performance is correct. (I.E., is the standard adequate)
  - **If it’s not correct – we may incur additional worker risk through can failure**
  - **We’re willing to incur additional worker risk to provide “extra confidence” that our failure model is correct**
  - **We need to know that packaging these materials to the standard does, in fact, equate to safe storage. If not, the standard must be changed**
- To identify (and presumably remediate) items that may contribute disproportionately to the overall risk.
  - **A identification mechanism must exists that allows for remediation with lower risk levels than that posed by failure.**

Why Surveillance?



- We must understand the potential mechanisms which lead to failure of package integrity
  - → **Failure (t) = Can (t) + Material (t) + Environment (t)**
  - → **Can could fail (corrosion)**
  - → **Material could force can failure (pressurization)**
  - → **Environment could force can failure (heat)**

Overall Approach

Program Elements	Address these issues	Effect Risk via:
Quality Assurance	Performance can only be ensured if the standard is actually met	S
Inspection of Packaged Containers in Storage	We can’t presume to think of every failure mode	S
	QA might not be perfect	CH
	May identify a “precondition” to failure	B
Detailed Studies on Representative Packages (materials and containers)	We can’t presume to think of every failure mode	S
	We don’t know the potential outcome of “transients”	CH
	We don’t understand the behavior of these materials well	S + CH

Program Elements : QA

- QA
  - → **Ultimately, we want good packages, so if the standard is adequate, we must ensure they meet the standard**
  - → **If items fail, but we are unsure if they were packaged to the standard, then we learn nothing about our failure model**
- QA and Package Failure
  - → **Inappropriate material preparation could lead to gas generation and pressurization-induced failure**
  - → **Welding or closure failure**
    - ✓ Relatively passive in storage, if QA is good then long-term performance should be good
  - → **Corrosion failure**
    - ✓ Relatively active in storage, so QA must focus on ensuring specified initial conditions

Program Elements : Detailed Studies

- This is the most effective means to establish the "failure model".
- We can obtain quantitative information.
- We are performing evaluation of materials "outside" of the specification (provides a measure of specification robustness).
- We can TRY to generate a controlled failure (through either corrosion or gas generation).
  - → **This helps us to understand how these postulated failures may manifest themselves.**
  - → **Allows us to eliminate altogether some potential outcomes**

Program Elements :
Inspection of Stored Packages

- Only this approach would allow us to “catch” a failure mechanism that we hadn’t thought of.
- This element can provide quantitative feedback on the performance of the QA mechanisms.
- This element provides a high level of perceived value added.
- This element can contribute significantly to worker exposure over package lifetime.

Determining a technically-based level of stored package inspection is the basis for the remainder of this presentation

Computing the Inspection Rate:

1. Identify *meaningful* failure criteria (something that we would be sure to know and want to avoid)
2. Evaluate time-evolution for these mechanisms (at a reasonable limit, how fast could pressure evolve)
3. Estimate what the “failure rate” might be - or the likely limits to failure rate (could it really be 1 in 100?)
4. Determine early-detection mechanisms and probabilities (e.g. even if we do radiography - what would we see?)
5. Evaluate potential action tracks for items failing a surveillance criteria (when does it make a difference and what do I do that’s different)
6. Compute risk associated with package failure and risk associated with identification (through surveillance) and remediation.
7. Consider what level of “confidence” is needed on information leading to low-probability/high-consequence events
8. Drive surveillance sampling rate to minimize overall risk coupled with “need to know” that low-probability/high-consequence events will not occur

How Does Inspection Rate Effect Risk

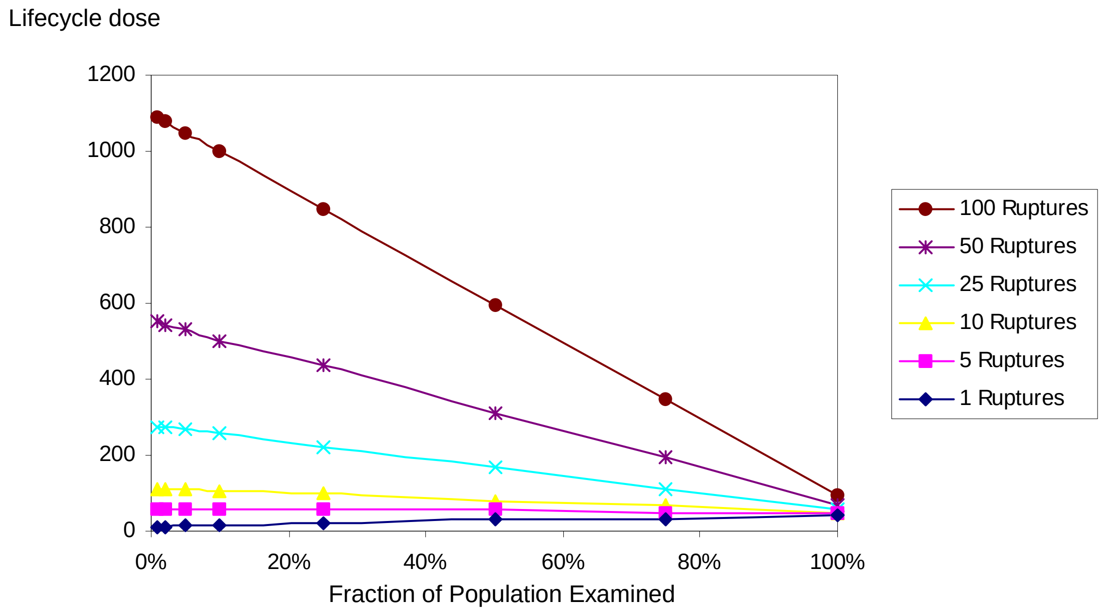
- **Surveillance increased risk by:**
  - → Remediation of cans that have been identified increases personnel dose and likelihood of re-introduction of new problems
  - → Increased worker dose
  - → Increased likelihood of “event” associated with increased handling
- **Surveillance reduces risk by:**
  - → Eliminated can ruptures associated with identification and remediation of these cans that would have ruptured.
  - → If identification of QA flaws or weaknesses in the standard occur before all packaging is finished, these practices could be corrected.

Elements of Worker Exposure

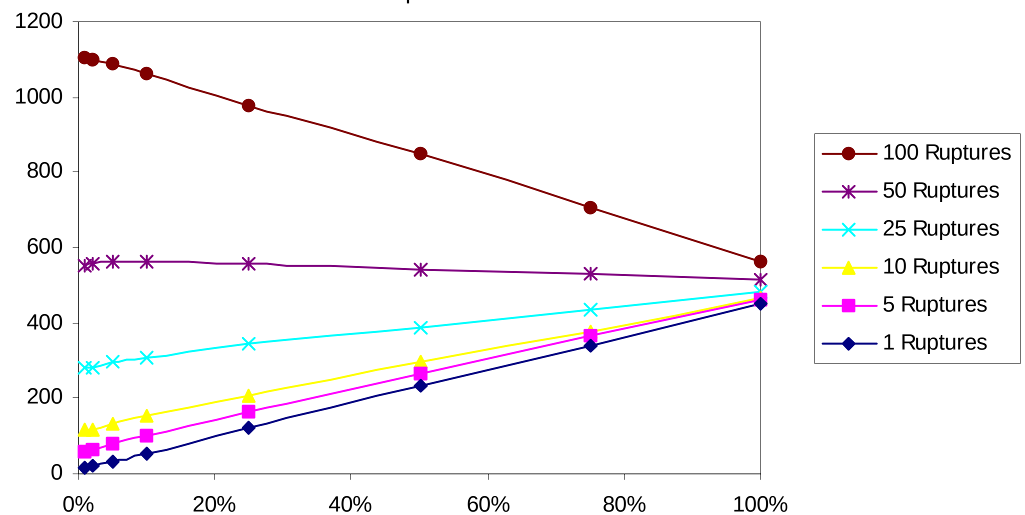
- Worker impact of can failure
  - → dose to workers associated with accident
  - → dose to workers associated with clean-up
  - → number of can failures we “expect” to happen
- Worker impact of inspection program
  - → dose to workers associated with routine surveillance operations
  - → dose to workers associated with remediation activities
  - → fraction of potential can failures we “expect” to identify through surveillance
  - → changes to packaging materials or processes to decrease likelihood of future can failures

An example calculation in terms of worker exposure

If the accident dose is 1000x the routine surveillance dose, we find that less surveillance is “better” for fewer than 10 expected ruptures



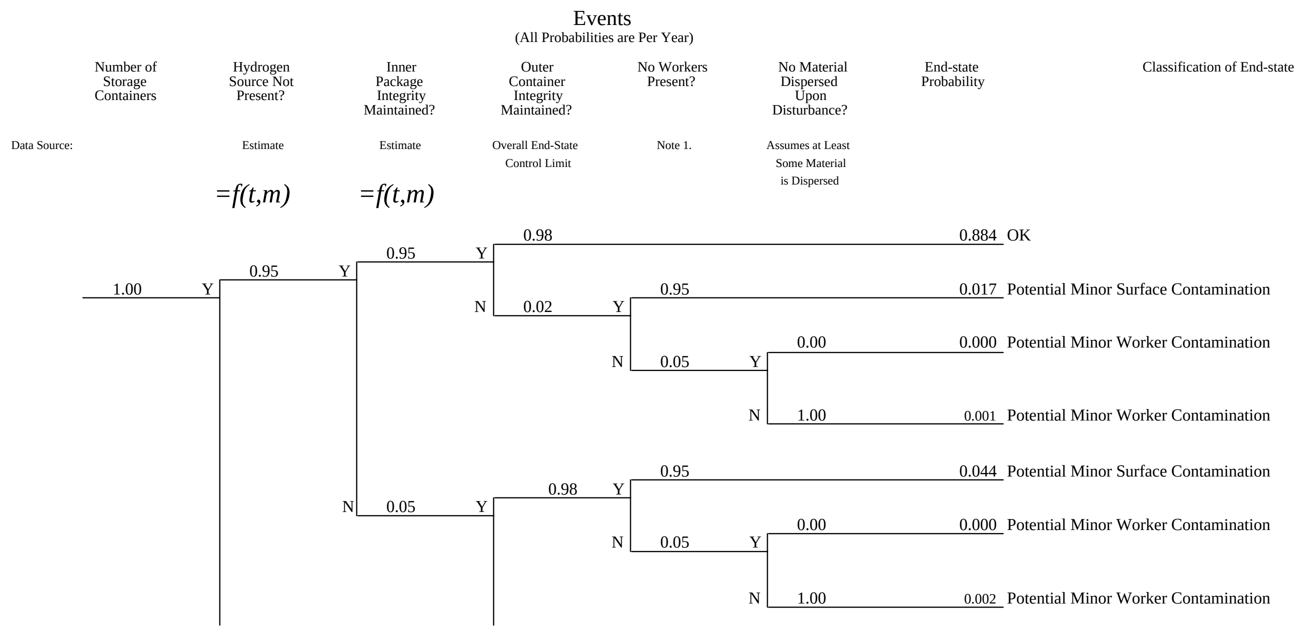
If the accident dose is 100x the routine surveillance dose, then surveillance improves the risk posture only if we expect more than 50 ruptures.



Estimating Package Failure Risk

- Two known failure mechanisms:
  - **Presence of a source for hydrogen gas generation**
  - **Container defects due to:**
    - Welding problems
    - Corrosion
- Determine the probability of end-states from probability of events leading to end-state.
- Two categories of events:
  - **Control limit events:**
    - Events that control the overall probability of end-states
    - Events that are monitored
  - **Uncontrolled events:**
    - Events that are unmonitored

Probabilistic Event Trees - Example of Partial Event Tree



This is an event tree for a particular point in time. Since it is anticipated that the uncontrolled event probabilities will vary with time, i.e. “bathtub curve”, to control the probabilities of the end-states, the control limits will vary as a function of time. For example, the control limits may be much tighter in the initial phases of the surveillance program requiring higher sampling rates to compensate for the infant mortality period.

Example Summary	
0.884	OK
0.109	Potential Minor Surface Contamination
0.007	Potential Minor Worker Contamination
0.003	Likely Minor Surface Contamination
0.000	Likely Minor Worker Contamination

Identification of Subpopulations

- Data is required to develop probabilities for uncontrolled events by subpopulations.
  - → **QA and Detailed Studies program elements are primary sources of information to lead to these estimates.**
- Subpopulations will be identified:
  - → **Based on characterization data and knowledge about the chemistry of the unstabilized plutonium-bearing materials**
- Subpopulations of Pu-bearing materials may have different confidence intervals on the control limits
  - → **This will reduce the number of samples required, and hence reduce worker exposure, for subpopulations when there is no credible physical mechanism for some of the events, such as hydrogen build-up**

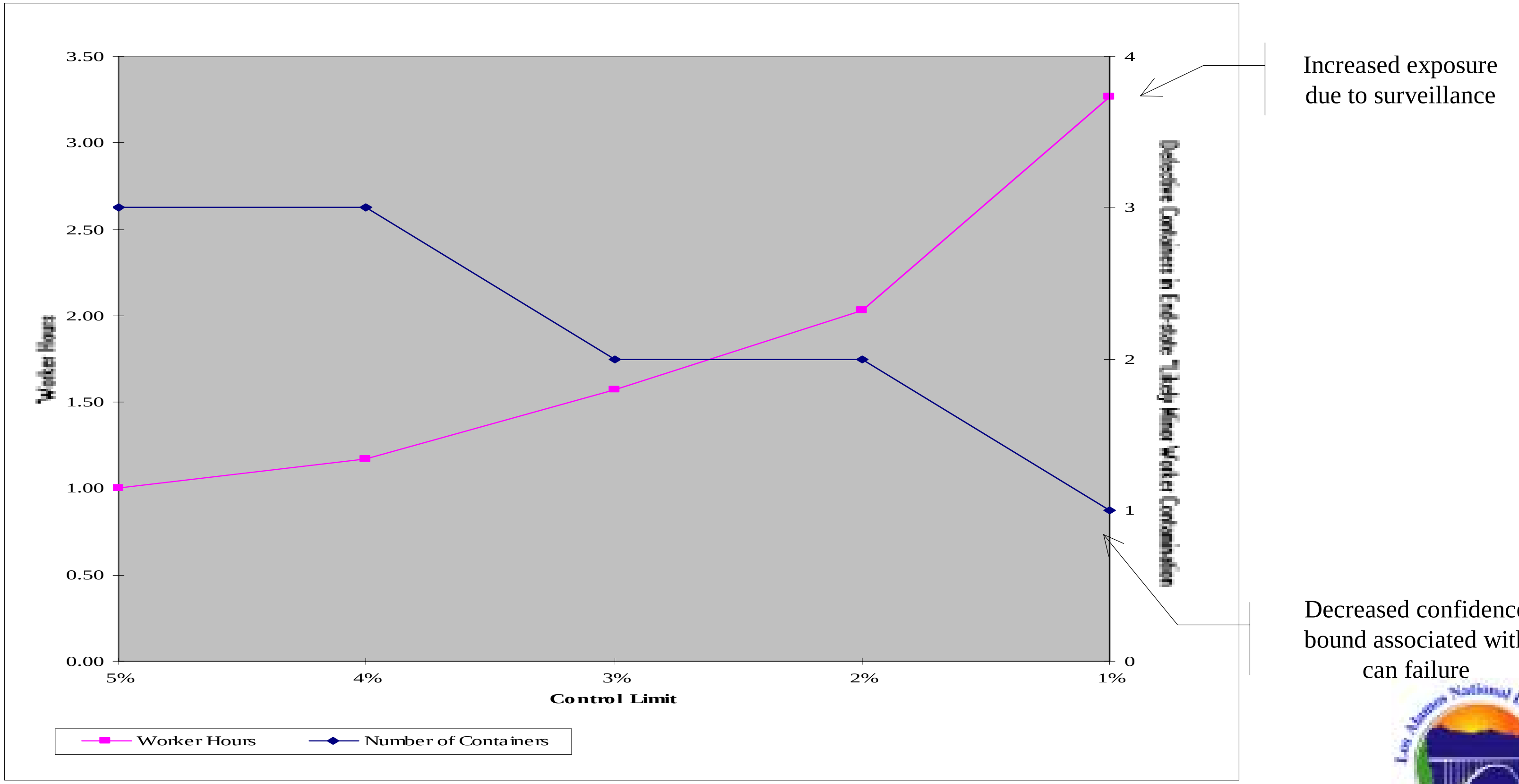
Sample Size Determination: Based Upon Information Requirements

- Initial control limit is based on finding NO defects in the sampled population.
- Hypergeometric sample size assumes that inspection is perfect, detection probability of 1.000, eg. in the example table. Sample size will be adjusted to account for detection probabilities.

Population Defective Threshold, M		Number of Defectives Observed: 0 in Sample	1 in Sample	2 in Sample	3 in Sample	4 in Sample	5 in Sample	6 in Sample	Population Size: 1,133
10%	114	28	45	60	74	87	100	112	
8%	91	36	57	75	92	109	125	141	
6%	68	48	76	100	123	145	166	187	
5%	57	57	90	119	146	172	197	221	
4%	46	71	111	147	180	211	242	271	
3%	34	95	148	196	239	281	321	360	
2%	23	138	214	281	343	401	456	509	
1%	12	250	383	495	597	689	775	854	
0.5%	6	445	659	825	959	1062	1124		
0.1%	2	880	1105						
0.0%	0	1077							

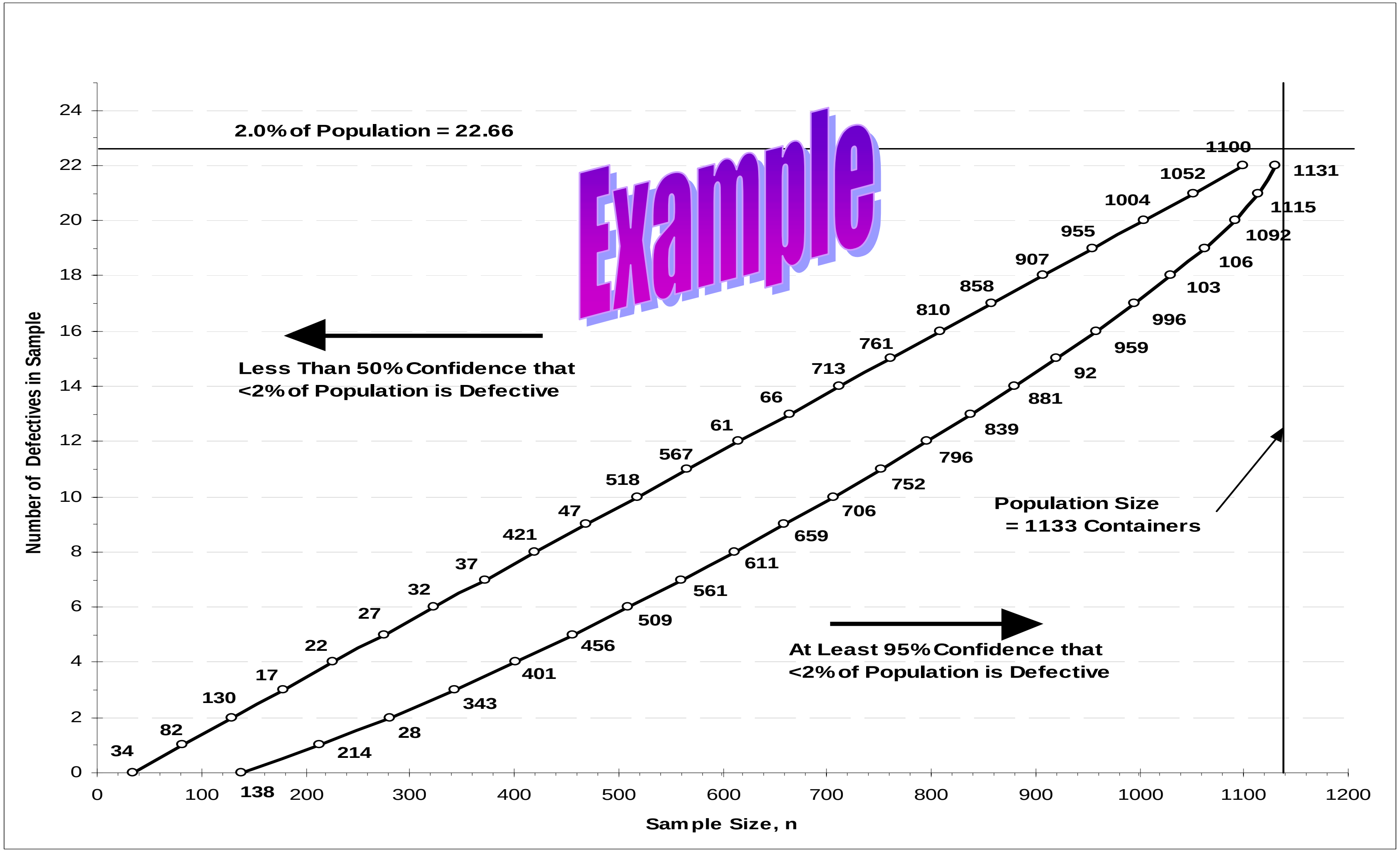
Sample Size Determination: Now Balancing Against Risk Estimates

- Number of samples is determined by a trade-off analysis between control limit and worker exposure.



Generation of “Decision Curves”

- Example of a graphical means for visually assessing the need for mitigation or additional sampling.



Summary

- DOE has developed a long-term storage standard for Plutonium
- Due to uncertainties in the performance of the standard and the packaged material, a Surveillance program is required
- The program couples 3 elements
  - → **Quality Assurance at Package manufacture**
  - → **Evaluation and Investigation of some members of the population**
  - → **Detailed studies on representative packages**
- The degree of effort on the Surveillance program can be technical driven to a point, but must ultimately rely on judgment concerning “degree of belief” in our understanding of material and package behavior. Hence the trade-off between “confidence” and the risk estimates.